11.7 An Integrated RFID Reader

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In an UHF RFID system, the reader transmits up to +30dBm of power to activate and communicate with the RF tags. A passive tag receives the transmitted signal, converts it to DC to build up its voltage supply, and then modulates its antenna impedance at 40-250kb/s rate to reflect the modulated signal back to the reader with an offset of 40 to 250kHz from the reader transmitter carrier [1]. Due to the simultaneous TX/RX operation and limited isolation (15 to 20dB), the TX output leakage results in an in-band blocker of +10dBm or more at the RX input. The reader receiver sensitivity is determined by the tag sensitivity level and the antenna efficiency. With typical sensitivities of –16dBm for passive and –22dBm for active tags, combined with a 20dB loss of the tag antenna at 900MHz; a total loss of 112dB/124dB from reader TX to passive/active tags and back to reader RX are calculated. This translates into signal levels as low as –82 and –94dBm, respectively, for passive and active tags at the reader RX input. Therefore, the main challenge in RFID reader design, especially for low-cost ICs, is to reliably receive the tag signal of –82dBm or less, in the presence of a strong TX leakage of higher than +10dBm only 40 to 250kHz away from the desired signal. This requires an RFID reader with an RX path that accommodates more than 90dB of dynamic range.

The blocker and its noise floor should be filtered to maintain the RX sensitivity and linearity performance. Present microwave technology fails to provide a highly selective filter to reject a blocker which is only a few hundred kHz away from the desired signal. The proposed reader front-end allows detection of the tag information in the presence of large in-band blockers, in a power efficient manner, based on the RFID range.

The RFID reader uses direct-conversion architecture (Fig. 11.7.1). For a near-field RFID (<3ft) where the tag backscattered power is much stronger than the reader sensitivity (>>–80dBm), a conventional gain/attenuation setting in the RF front-end would be adequate to detect the desired signal in the presence of the large TX blocker.

However, for a far-field RFID (>3ft) for which the desired signals levels are closer to RX sensitivity of -80dBm, the conventional gain/attenuation technique fails. In this case, the proposed reader architecture allows for amplification of the weakest desired signal by 18dB while rejecting the TX blocker and its noise floor as well as LO phase noise by 30dB on average, resulting in a better than 50dB of signal-to-blocker ratio. TX blocker rejection is achieved through a combination of two RF paths. A linear path amplifies both the desired signal and blocker equally through an LNA and a nonlinear path limits both blocker and the desired signal. The limiting function only preserves the frequency and phase of the stronger signal which is the blocker. The blocker is then rejected by subtracting the outputs of the linear and nonlinear paths. Therefore, the blocker is cancelled out but the desired signal is amplified through the linear path. The blocker rejection depends on the delay and gain mismatch between the two paths. Since, by design, the delay difference between the linear and nonlinear paths is less than a few percent of the carrier period, no phase adjustment is needed. A calibration engine adjusts the nonlinear-path gain to match the linear-path gain. This is accomplished using two received signal-strength-indicators (RSSIs) by monitoring the blocker level at the common input and output of the two paths, and using LMS algorithm implemented in an FPGA.

In this scheme the desired signal gain depends on the phase difference between the blocker and desired signal. For a phase difference of ‘θ’, the desired signal gain is ‘$g_{LNA} \cdot \cos\theta$’. Due to the wave propagation in air, the backscattered signal phase, i.e., $4\pi d/\lambda$, depends on the TX carrier wavelength. To further align the signal/blocker phases and hence maximize signal-to-blocker ratio, the TX carrier hops to provide additional phase shift of $4\pi d\Delta f/c$, where Δf is the hopping step. A maximum frequency hopping of 25MHz for a distance of 9ft, creates a 90° phase shift.

To filter out the blocker and LO phase noise after the LNA/limiter, I/Q mixers downconvert the RF signal to baseband using the TX output as RX LO. This results in totally correlated phase noise of RX LO and blocker. Therefore, the total phase noise/noise floor of the TX front-end and VCO are folded to DC and do not overlap with data frequency band from 40 to 250kHz. A DC-offset cancellation circuit then rejects the baseband noise.

Figure 11.7.2 depicts the circuit schematic of the LNA and the limiter. They share the matching network to minimize the delay mismatch between the linear and the nonlinear paths. The only delay mismatch therefore comes from the input transconductances (g_ms) of the LNA and the limiter, which is on order of $1/f_t$, i.e., less than a few picoseconds. The input matching network consists of a 50Ω on-chip resistor (R_{M1}+R_{M2}) and an LC BPF (L_M, C_M) at 900MHz. The LNA has a main g_m (that of transistors M_1 and M_2) that corresponds to LNA high-gain mode and a secondary g_m (that of transistors M_3 and M_4) that corresponds to LNA low-gain mode. Transistors M_1 and M_2 remain linear for input blockers up to +10dBm. Larger blockers of +10 to +20dBm could saturate both the LNA output (which is handled by injection) and the LNA input g_m, of transistors M_1 and M_2. In this case RX uses the second g_m (that of transistors M_3 and M_4), after a resistive loss of $20\log[R_{M2}/(R_{M1}+R_{M2})]$ (low gain). The input RSSI determines which input stage is ‘on’.

Input transistors of the limiter, M_{Lim}, are highly nonlinear (switching mode) and driven by the large blockers rather than the weak desired signal. The current subtraction at low-impedance node of cascoded devices avoids large current excursion in M_{CAS}, ensuring negligible flicker noise upconversion of M_{CAS} to RF, not to degrade the RX NF.

The reader gain and NF in the presence of –10 to 10dBm blockers with and without injection is shown in Fig. 11.7.3. Without injection, data gain drops by 25dB for a 10dBm blocker. However, injection maintains a flat data gain of 18dB and average NF of 12.6dB for wide range of blockers, while rejecting the blocker by 30dB (on average).

As shown in Fig. 11.7.4, for blockers larger than 10dBm, transistors M_3 and M_4 exhibit superior gain and NF as compared to transistors M_1 and M_2. This superior performance also holds with a 30dB fixed loss (Fig. 11.7.4). For a 19.2dBm blocker, injection plus resistive loss improves the gain and NF by 10 and 15dB, respectively, as compared to pure injection and 30dB fixed loss. Figure 11.7.5 shows the sharp front-end frequency response with 30kHz of stopband at 900MHz for a 10dBm blocker with injection ‘on’. The data gain drops 1.2dB because of partial AM-PM mechanism in the limiter.

The above measurements are taken with in-phase data/blocker at 900MHz. Shifting the data/blocker phase drops data gain by 27dB (Fig. 11.7.6), however, TX carrier hopping from 900 to 925MHz recovers it back to 18.6dB, while retaining the blocker rejection. Therefore, TX carrier hopping based on tag acknowledgement, provides maximum signal-to-blocker ratio for a far field RFID. The RFID reader IC is fabricated in a 0.18µm CMOS technology. The die micrograph is shown in Fig. 11.7.7. It occupies an area of 2.1mm^2 and draws 40mA with limiter ‘off’ and 56mA for maximum rejection of a 20dBm blocker from a 3.3V supply voltage.

Reference:

[1] K. Finkenzeller, RFID Handbook-Fundamentals and Applications in Contactless Smart Cards and Identification, 2nd Ed., John Wiley & Sons, 2003.

 1-4244-0852-0/07/$25.00 ©2007 IEEE.

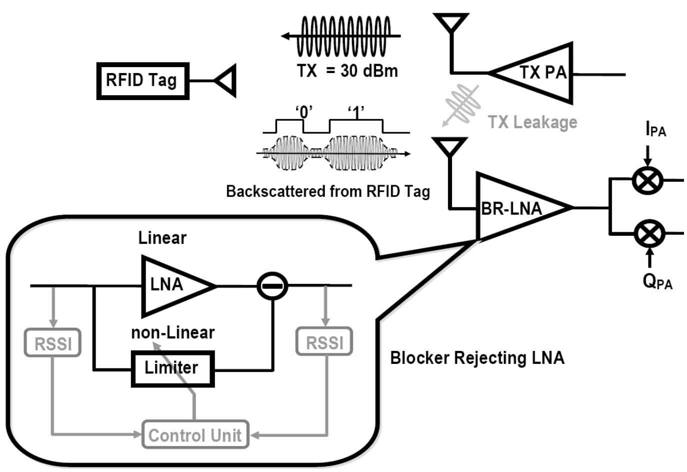

Figure 11.7.1: RFID system and the proposed RFID reader front-end.

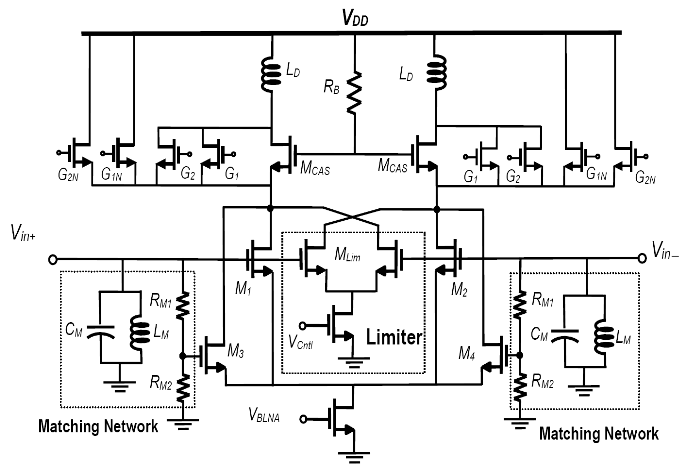

Figure 11.7.2: LNA and limiter with resistive inputattenuation and gain settings of G_1, G_2, G_{1N}, G_{2N}.

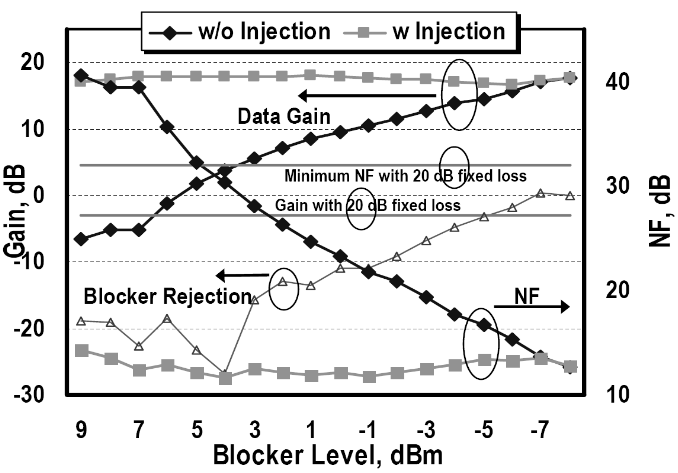

Figure 11.7.3: RFID reader front-end gain and NF: with and without injection measured for blockers of -10 to 10dBm.

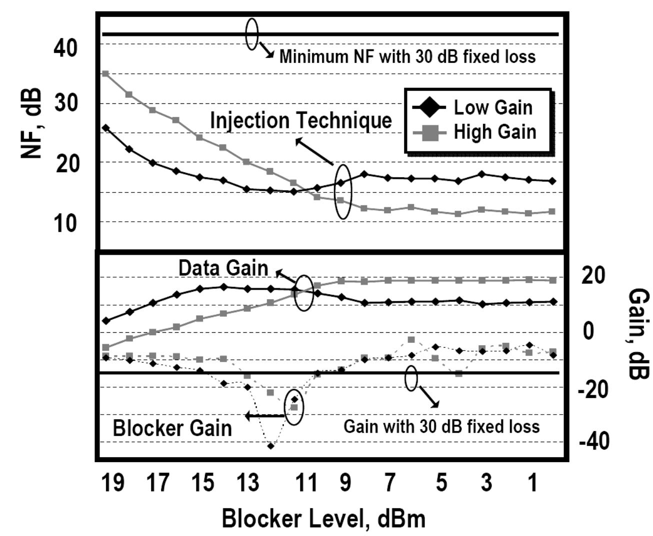

Figure 11.7.4: RFID reader conversion gain and NF, in 'high' and 'low'gain modes for blockers as high as 10 to 20dBm.

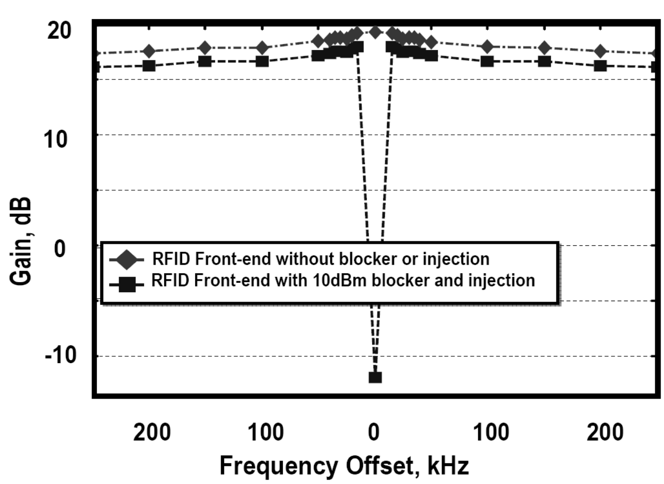

Figure 11.7.5: RFID reader front-end frequency response: without blocker or limiter and with a large blocker of 10dBm and limiter turned 'on'.

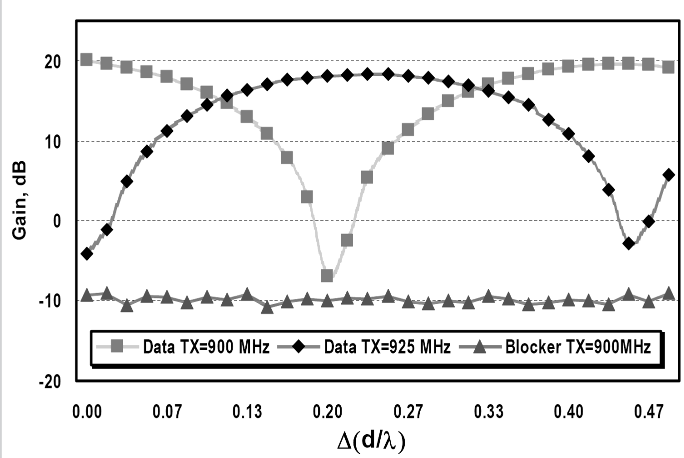

Figure 11.7.6: RFID reader data and blocker gain for TX frequency hopping versus data and blocker phase difference (blocker = 10dBm).

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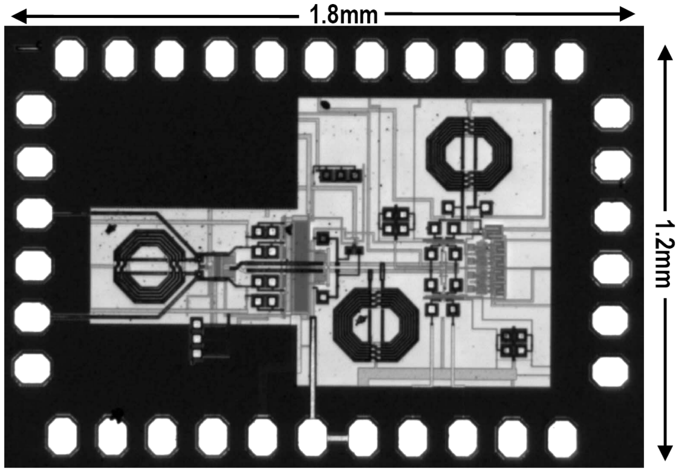

Figure 11.7.7: Die micrograph of the RFID reader front-end(1.8×1.2mm²).

